

EVALUATING THE ENERGY CONTENT OF INGREDIENTS IN POULTRY DIETS – AN UPDATE

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Summary

The methodology currently in use to evaluate the energy content of ingredients, under practical situations, needs improvements to increase the accuracy of the estimation, reduce safety margins, and improve feed cost. Different methods can be used to estimate the energy values of the ingredients and diets. The method most widely used worldwide to estimate the energy content of the ingredients is the use of tabulated values but most companies involved in poultry production are moving towards the use of predictive regression equations based on chemical analyses and in vitro and in vivo data. More research to improve the accuracy of systems in use for the estimation of the energy content of poultry feeds is needed. Also, we need a better knowledge of the many factors that affect energy values. The final objective is to implement an easy method to predict more accurately the energy content of the feeds using on line NIR technology.

Introduction

Feed energy is one of the major cost in the production of eggs and poultry meat. Accurate evaluation of the energy content of the ingredients is fundamental to reduce feed cost. Apparent metabolizable energy corrected for nitrogen retention (AMEn) is widely used for feed evaluation in most countries (HILL AND ANDERSON, 1958; VOHRA, 1972; CHOCT, 2012) but the system might not work properly under all circumstances (VAN DER KLIS and FLEDERUS, 2007). As a consequence, many scientists advocate for the use of net energy systems to better estimate the energy content of the ingredients (DE GROOTE, 1974; NOBLET et al., 2010; CHOCT, 2012). In practice, the 3 main approaches used to evaluate the energy content of ingredients in poultry diets are based on values obtained from a) tables, b) predictive equations (in vitro studies, wet chemistry, or NIR technology), and c) in vivo experiments (research farms). Each of them has advantages and disadvantages and at present time, it is not easy to make a fair recommendation on which one is best. In practice, many feed mills use table values to estimate the energy value of the ingredients. However, most of the nutritionists and feed mill managers from key European companies and broiler integrators are moving to evaluate ingredients energy by using predictive regression equations. Finally, the in vivo trials are time consuming and expensive, and not always the data are consistent and accurate overtime, especially in the case of soybean meal, wheat, and lipid sources (BOURDILLON et al., 1990; YEGANI and KORVER, 2012; FRIKHA et al., 2012; RAVINDRAN et al., 2014). Consequently, the use of in vivo trials is not common in commercial operations. In any case, none of these systems is free of problems. Many factors, including feed technology (i.e., particle size, heat processing, and feed form) (MCKINNEY and TEETER, 2004; SKINNER-NOBLE et al., 2005), diet composition including fat inclusion (MATEOS and SELL, 1980; MATEOS et al., 1982), type of cereal (YEGANI and KORVER, 2012), use of whole wheat (RAVINDRAN et al., 2006), and additives (ANNISON, 1991; MATEOS et al., 2002) modify in different ways, the energy content of the ingredients in practical diets. In the current presentation we will focus on practical problems encountered by the industry when using Institutional tables, predictive regression equations, and in vivo values for key ingredients, namely cereals, soybean meal, and fats.

Table values

In spite of the wide criticism, the use of table values is the main used worldwide to evaluate the energy content of ingredients and feeds. Table values provided by recognized, institutional sources, are of value. In fact, the approach might be the most adequate for ingredients with limited information published and not many own lab analyses available. However, the wide range in energy values proposed by the different Institutions for a given ingredient is of concern. Examples for SBM, corn, rapeseed meal, and DDGS are shown in Tables 1 to 4, respectively. In some cases, the variability in energy values can be justified by differences in the CP and antinutritional factors (ANF) content (i.e., rapeseed meal tables), the moisture of the grain (i.e., corn), or the nature of the heating process used (e.g., soybean meal). However, the wide range of values (e.g., 230 kcal AME/kg for SBM and 850 kcal AMEn/kg for corn DDGS) detected in some other cases deserves a thorough revision.

Table 1. AMEn content of soybean meal

Institution	Country	Year	CP (%)	AMEn (kcal/kg)
NRC	USA	1994	47.2	2,380
INRA	France ²	2002	47.2	2,340
NARO	Japan	2009	47.1	2,450
FEDNA	Spain	2010	47.5	2,380
CVB	Neth. ¹	2011	47.5	2,220
ROSTAGNO	Brazil ²	2011	47.0	2,320
MPA ³	Russia	2014	47.0	2,300

¹Estimated from offered values²Average of broilers and laying hens³Russian feed tables**Table 2.** AMEn content of corn for poultry

Institution	Country	Year	Moisture (%)	CP (%)	EE (%)	AMEn (kcal/kg)
NRC	USA	1994	11.0	8.5	3.8	3,350
INRA	France ²	2002	13.6	8.1	3.7	3,200
FEDNA	Spain	2010	13.8	7.7	3.6	3,280
Rostagno	Brazil	2011	12.5	7.9	3.7	3,380
CVB	Netherlands	2011	12.8	8.2	3.8	3,294

¹HCl hydrolysis**Table 3.** AMEn content of rapeseed meal expeller in poultry

Institution	Country	Year	CP (%)	AMEn (kcal/kg)
NRC	USA	1994	38.0	2,000
INRA	France ²	2002	33.7	1,440 ²
Premier	UK	2008	33.9	1,670
NARO	Japan	2009	37.3	1,740
FEDNA	Spain	2010	33.8	1,700
CVB	Neth.	2011	33.5	1,580 ²
MPA ³	Russia	2014	35.5	1,800

¹12.5 to 5.0% ether extract²Average³Russian feed tables**Table 4.** AMEn content of corn DDGS in poultry

Institution	Country	Year	CP (%)	EE (%)	AMEn (kcal/kg)
WPSA	Europe	1986	25.0	6.5	2,380
NRC	USA	1994	28.5	9.0	2,930
INRA	France ²	2002	24.6	5.1	2,190
NARO	Japan	2009	30.8	11.0	2,170
FEDNA	Spain	2010	26.6	10.1	2,350
CVB	Neth.	2011	27.0	10.0	2,070

¹HCl hydrolysis

Use of predictive regression equations

Regression equations are becoming popular for the evaluation of the energy content of feedstuffs and used consistently by major companies involved in animal feeding. The implementation of predictive equations reduces the workload for diet formulation under all circumstances, but it is of primary interest in these companies or integrators with different feed units and high number of recipes. Regression equations are easy to implement, allowing for the updating of feed ma-

trixes of the ingredients in use and facilitating the use of lab data into the feed formulation process. However, under practical conditions and certain circumstances, some problems might arise.

1) The regression equations were obtained using samples belonging to a different population or it is of “unknown” origin.

2) The summation of lab analyses of the major dietary components of the ingredient (moisture + ash + CP + EE + NDF + sugar + starch + soluble fiber) do not add to 100%.

3) The equations used include chemical values but potential differences because of effects of processing on nutrient digestibility (i.e., heat processing of SBM or DDGS) or method of analyses applied (i.e., polarimetry rather than enzymatic process for starch and HCl hydrolysis for fat) have not been taken into consideration.

4) Predictive equations in use had a small r and a high RSD values. This situation is frequent when the batches of the ingredient used have a narrow range of values within samples (i.e., trypsin inhibitor content of commercial SBM samples).

The use of predictive equations obtained with a set of samples of a different population is quite common, and will result in inaccurate estimation of the energy value. For example, in many instances the same equation is used for grain by-products that have been obtained by different processes (i.e., temperature and heating conditions). A situation that deserves special attention is the estimation of the energy value of SBM to be received in coming months from the values of samples collected in the previous month. The information needed is not the value of the SBM of the last vessel but to know in advance, the characteristics of the meal at the arrival to the port of the new vessel.

A problem often found, especially in small, local feed mills, relates to the use of chemical lab analyses in which the sum of all proximal analyses vary widely from 100% to predict the energy value of a novel or local ingredient. Under circumstances of poor lab analyses (below or higher, depending on potential errors), the misuse of the ingredient in diets is warranted, with important economic and/or production losses.

Evaluation of the energy content of cereals

Cereals are the main source of energy in commercial poultry diets worldwide. Consequently, the accurate determination of its energy content is of paramount interest. However, the discrepancies among authors, when estimating the energy content of cereals, such as corn and wheat, by using tabulated values, predictive regression equations, or in vivo data (FARRELL, 1999; YESANI and KORVER, 2012) are wide. For example, moisture content is probably the main constituent affecting the AMEn content of corn (See NRC, 1994 value in Table 2). However, not in all labs, the moisture content of the cereals is analyzed in a correct form. Moreover, not always moisture content is taken into consideration when estimating the energy content of the corn under practical conditions. For wheat, energy data is even more variable, with samples analyzed in the same lab varying often between 50 and 70% (ABDOLLAHI et al., 2011; YEGANI and KORVER, 2012). Factors such as variety (hard vs. soft), length of storage (new crop vs. old crop), ANF content (xylanase level and type), diet composition (level and type of fat), and age of the birds, might impact the energy content of the cereal. Consequently, the practical interest of determining the energy content of the cereals in vivo, is not always justified.

Evaluation of the energy content of soybean meals

A good example of the advantages and disadvantages of the use of predictive regression equations to evaluate the AMEn content of protein sources is that of the European table of energy values for poultry feedstuffs (WPSA, 1986) and its recommendation for SBM. This equation ($\text{AMEn (kcal/kg)} = 37.5 \times \text{CP} + 46.4 \times \text{EE} + 14.9 \times \text{NFE}$) is widely used and recognized as a good tool to evaluate the energy content of the meals in poultry. However, this equation, created 25 years ago, might not be as precise as needed and thus, the interest of its use might be limited in commercial current situation. For example, the same equation is recommended for all SBM, independent of the origin of the beans. However, several reports (MATEOS et al., 2011; FRIKHA et al., 2012; RAVINDRAN et al., 2014) clearly indicate that the chemical composition, and therefore the energy content, varies with the country of origin of the meal, an effect probably related with day length (latitude), soil characteristics, and growing and storage conditions of the beans. In this respect, MATEOS et al. (2011) and FRIKHA et al. (2012) have reported that for meals with similar CP content, those of USA origin had more sucrose and oligosaccharides and less NDF than those from Brazil origin. Moreover, process conditions applied for the crushing of the beans will also affect the AMEn content of the meal. Under-heating of the beans will reduce the energy content of the corresponding meal, because of the presence of high amounts of TI in the meal,

whereas over-heating will reduce this level of TI but at the expense of a higher incidence of Maillard reactions. However, the European equation equalizes the energy content of SBM from different crushing plants, independent of the heating conditions applied during the processing of the beans and the final quality of the protein fraction.

A second problem related to the use of the WPSA (1986) equation for SBM, relates to the ether extract part of the equation. Energetically, EE is an important constituent of the bean and has to be taken into account when evaluating the energy content of a meal. However, the equation does not take into consideration several points of interest. For example, the real fat content of the EE fraction varies depending on the amount of lipids left in the meal. Also, different lipid fractions (e.g., acid soapstocks, lecithins, gums) might be used to increase the fat content of the SBM. Finally, the use or not of previous HCl hydrolysis by the lab, will give different EE content of the meal (up to 1% higher). A last concern with the use of the WPSA (1986) equation is the use of nitrogen free extract (NFE) as a part of the equation. This fraction does not mean much from a nutritional point of view. It obtained by difference between 100 and the proximal analyses contents. Therefore, it includes 2 sources of variation: a) no distinction among components, giving the same energy value to lignin, pectins, or other more digestible components and b) all mistakes that might occur during the calculation process, including errors in lab analyses will have a positive (or negative) effect on energy evaluation. Thus, NFE should not be included in predictive regression equations to estimate the energy value of any ingredient. Intuitively, a good equation to determine the AMEn of a given batch of SBM should include the amount of digestible protein (not good lab methods available yet) and the amount of sucrose of the sample. Also of interest, could be the inclusion in this equation of real fat content (quite similar for all solvent meals marketed in the EU-28 but of interest for expeller meals or solvent meals that add other lipid fractions) and the content in oligosaccharides (stachyose and raffinose). Oligosaccharides (around 7% of the meal on DM bases) are not digested by the bird but will be fermented at some extent on the cecum, being a good source of energy, especially in laying hens.

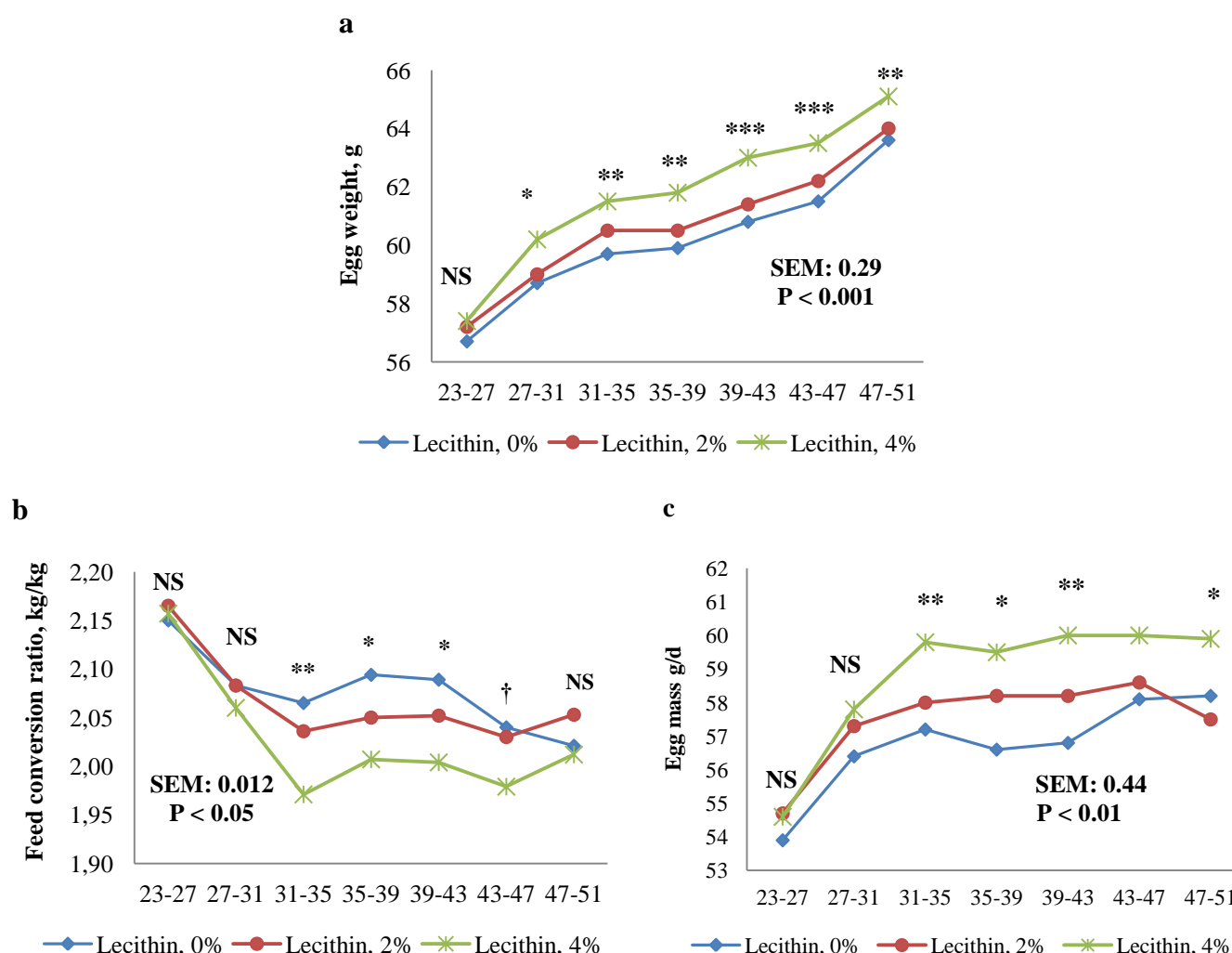
Evaluation of the energy content of lipid sources

The use of lipid sources have increased steadily in poultry diets in the last decade. The main factors affecting the energy content of oils and fats are the chemical quality (including among other variables, the gross energy, moisture, impurity, and unsaponifiable content, and the peroxide value) and the characteristics of the molecule (namely, proportion of free fatty acids (FA), degree of unsaturation, and length of the carbon chain). Most of the data available on the energy content of fats and oils were obtained more than 30 years ago and consequently, the practical application of these values to the new standards of feed formulation and sources of fats (i.e., lecithins and blended fats) might not apply in some occasions.

Recent research conducted in our lab (MANDALAWI et al., 2015, unpublished data) has shown that the inclusion of lecithins in laying hen diets improved the AMEn content of the feed more than expected. In fact, the substitution of animal fat by soy lecithins, increased egg weight and improved feed efficiency (Figure 1). Probably, the lecithin, a lipid source rich in phospholipids and unsaturated FA, improved bile production and micelle formation, facilitating the incorporation of the FA into the yolk.

Fats are the most difficult ingredient to evaluate in poultry diets, the main reason being problems in the *vivo* determination of their energy content. Fats are incorporated into the experimental diets at low levels (usually less than 6-8%) and consequently, the experimental errors magnifies differences in energy values among lipid sources. Moreover, in many cases the control diet is based on corn that contains appreciable amounts of intracellular oil which might have different digestibility (usually lower) to that of the fat source tested (IRANDOUST et al., 2012). Consequently, the experimental error is large in fat digestibility studies, which in turn might explain, at least in part, the wide difference in values reported by different authors for a given source of fat and AMEn values of a fat beyond its GE content. In addition, it has been shown that the inclusion of fat in the diet might improve the digestibility and utilization of other components of the diet (MATEOS et al., 1980), which adds new confusion to energy determination. Consequently, new approaches are needed to better estimate the energy content of fat sources in poultry diets.

Figure 1. Effect of inclusion of soy lecithin in the diet on egg weight (a), feed conversion ratio (b), and egg mass (c) from 23 to 51 wk of age.



Interactions among dietary components

One of the main assumptions of the AMEn system is the additivity of the energy values of the ingredients within a given formula. However, this assumption might not be correct. For example, the inclusion of fat (level and type) and fiber, the presence of contaminants and ANF, and the use of additives, including enzymes (phytases, carbohydrases, and proteases), organic acids, and others might modify the energy value of ingredients and diets

Fat supplementation reduces the rate of passage of the digesta through the GIT, which in turn might favor the utilization of the components of the diets, including the lipid, carbohydrate, and protein fractions (MATEOS et al., 1980). For example, the inclusion of unsaturated fats might improve micelle formation and the utilization of the saturated fat present in the constituents of the diet, contributing to the “so called” extra caloric effects of the fat.

Dietary fiber has been considered as an ANF factor in diet for poultry, because of its negative effects on palatability and nutrient digestibility. However, recent research (HETLAND et al., 2003, 2005; GONZÁLEZ-ALVARADO et al., 2007; JIMÉNEZ-MORENO et al., 2009; MATEOS et al., 2012) has shown that this might not be the case, and that under certain circumstances, the inclusion of small amounts (2-3%) of insoluble fiber sources in diets low in fiber, might improve nutrient digestibility and growth in broilers and young pullets.

The presence of ANF, contaminants (i.e., mycotoxins), or toxic components (i.e., heavy metals) in an ingredient affects nutrient digestibility and therefore, its energy content. The presence of ANF in the diet affects not only the energy of the ingredient “per se” but also that of the remaining components of the diet, because of its negative effects on the digestive mucosa and GIT function.

Additives are widely used in poultry feeding, especially in diets for young chicks (MATEOS et al., 2002). In many instances, the companies responsible for the research on the potential benefits of these products create matrixes for the additive that include “energy equivalent values”. These matrixes facilitate the work of the nutritionist, but are not free of problems. When several additives, each of them with its own matrix are incorporated into the diet, the “matrix approach” is probably not correct, because the potential benefits of the additives (i.e., exogenous enzymes, probiotics, prebiotics, essential oils, organic acids, etc) on energy are not additive.

Heat processing, mean particle size, and feed form

Grinding and heat processing of the cereals results generally in an improvement in the energy value of ingredients in young chicks but the effects tended to disappear with age (GRACIA et al, 2003; FRIKHA et al, 2013). Pelleting affects the AMEn of the diet, probably by modifying the structure of the fiber fraction (i.e., increasing the solubilization), releasing the lipids inside the cells (i.e., toasted soybeans and corn), and improving carbohydrate digestibility (i.e., pea starch) (ABDOLLAHI et al., 2012; SERRANO et al., 2013). Moreover, feed form of the diet and particle size of the ingredients, affect GIT development and function, mainly that of the gizzard. Also, diet characteristics modifies the rate of passage of the digesta through the GIT, which in turn might alter microbiota profile and the energy content of the feed (AMERAH et al., 2007; SVIHUS, 2011; MATEOS et al., 2012). However, the effects of feed form and particle size are not uniform. In fact, the benefits of fine grinding are less evident (and even negative) with the use of mash diets (ABDOLLAHI et al, 2011; SERRANO et al, 2013). Also, pelleting improves feed intake and broiler growth, but not always nutrient digestibility or AMEn content of the diet (ZELENKA, 2003). Recent research has shown that often the beneficial effects of pelleting reflects a lower feed wastage and feed intake and not necessarily an increase in the AMEn content of the ingredients (ABDOLLAHI et al, 2001; SERRANO et al, 2013). As a result, the AMEn of the diet might not be uniform and will depend not only on the ingredient composition and the physical and chemical characteristics of the diet but also on the health status of the bird. All these components are difficult to evaluate and add uncertainties to the real energy contribution of ingredients in poultry diets.

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